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(54) Guidance system for horizontal drilling

(57) The invention relates to horizontal directional drilling systems (14), in particularly guidance systems therefore. Such guidance systems, according to the invention comprise at least one of the sensors: fiber optic gyroscope (18,20,21), ring laser gyroscope, micro-electromechanical system and rate sensor (25). A microcontroller (9) is present for receiving and processing data from sensors at the drill head. The microcontroller (9) comprises neural fuzzy control logic for processing the data from the sensors at the drill head. Data from the microcontroller are sent to a surface based computer via radio-waves. The user interface in the computer (4) displays azimuth, tilt, and inclination angles of the drill head on the display device. The use of fiber optic gyroscopes and ring laser gyroscopes allows the display of true North and actual and desired tracks on the display device. Means are present for determining a reliability figure for data dependent on integrated signals from rate sensors and such reliability figures are displayed on the display device.

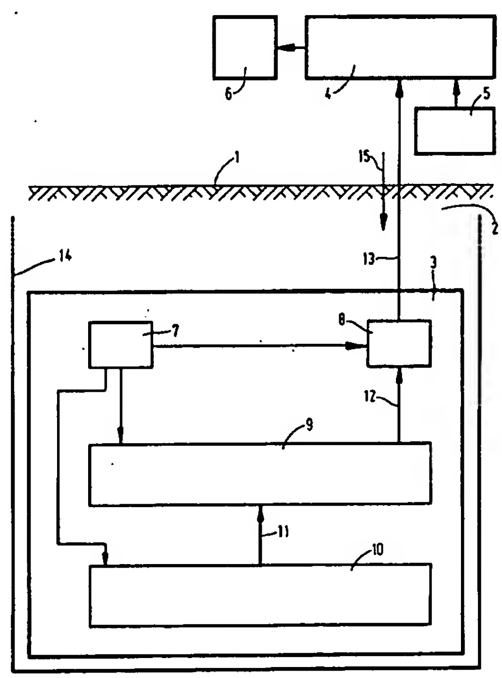

FIG. 1

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Description

Background:

[0001] The invention relates to a horizontal directional drilling.

[0002] Horizontal directional drilling is a method that is used in the laying of underground cables or pipes. The horizontal directional drilling method does not need trenches. A bore hole is made in horizontal direction at the position where the underground cable, pipe, etcetera has to be layed. In this way cables, pipes, etcetera are layed crossing railways, highways, waterways, etcetera. Drilling starts at a drilling starting point outside the bore hole to be made. Horizontal directional drilling systems need a guidance system to guide the drill head to a desired position. Two types of guidance systems are known. A first known guidance system is integrated in the drill head. A second known guidance system is the so-called walk-over system in which at the surface provisions are made to locate the drill head. A typical example of a walk-over system is known as the TruTracker system in which an artificial magnetic field is created at the surface and detected by magnetometers in or near the drill head. The reference point for the actual drill head position is the drilling starting point. The position of the drill head is continuously estimated, based on the actual drill head angles and the starting point by dead reckoning. Guidance systems integrated in the drill head assembly are based on sensors, which are moving down-hole together with the drill head. Such sensors measure the direction of the drill head in space, i.e. the azimuth angle (yaw), the tilt angle (roll) and the inclination angle (pitch). Present sensors, available on the market, are magnetometers, accelerometers and mechanical gyroscopes. The azimuth angle is measured by a magnetometer which uses the earth magnetic field to determine the azimuth angle relative to the earth magnetic field. The tilt angle and the inclination angle are measured by accelerometers. Accelerometers measure the earth gravity. When the sensor direction is parallel to the gravity field a value of 9.8 m/s^2 is measured. When the sensor direction is perpendicular to the gravity field a value of 0 m/s^2 is measured. An output of an accelerometer varies with the angle with respect to the earth gravity field according to the sine of the angle between the sensor and the earth gravity field. In this way the tilt angle and the inclination angle of the drill head can be measured. Traditional accelerometers have resolutions in the magnitude of 5 micro g. (1 g equals 9.8 m/s^2) and temperature coefficients in the magnitude of 75 micro g/degr. Centigrade. A typical guidance system integrated in the drill head assembly therefore comprises a magnetometer to determine the azimuth angle and two accelerometers to determine the tilt angle and inclination angle. Magnetometer readings of the azimuth angle are not always correct. In areas with underground magnetic constructions or electric power cables, underground or at the surface a lot of magnetic interference exists disturbing a correct azimuth angle reading by the magnetometer. Walk-over systems, such as the TruTracker system mentioned above, may avoid the consequences of magnetic interference. For example, the TruTracker system induces a magnetic field by wires at the surface. Thereby an artificial magnetic field is created overcoming many interferences. A disadvantage of walk-over systems is that they can only be applied when there is sufficient access to the surface overhead the drill head. Such sufficient access for example is not available when the bore hole has to be drilled under rivers with heavy ship traffic, highways or railways. Guidance systems in which use is made of mechanical gyroscopes do not suffer from the disadvantages mentioned herein before related to the use of magnetometers. A disadvantage of mechanical gyroscopes presently available is that they have relatively large dimensions. Because of those large dimensions and further because of their need for placement on a stabilized platform mechanical gyroscopes cannot be used for guidance in the initial bore hole. Consequently mechanical gyroscopes are only used for survey activities after the bore hole has been drilled already. Moreover mechanical gyroscopes are not suited for the harsh environment during drilling. In horizontal directional drilling accuracies of better than 30 centimeters for crossings with a length of 400 meters are required. The above described present guidance systems cannot achieve such accuracy. Magnetometers (when not interfered) and mechanical gyroscopes have an accuracy in the magnitude of 0.5 degrees. However in order to reach an accuracy of better than 30 centimeters over 400 meters an azimuth accuracy in the magnitude of 0.03 degrees is required. Not only the guidance systems do not achieve the required accuracies but also the skills of the personnel controlling the horizontal directional drilling systems plays an important role. Especially in magnetically contaminated areas, i.e. areas with a lot of magnetic interference, highly experienced personnel is required to achieve an acceptable level of accuracy. But even with highly experienced personnel in magnetically contaminated areas location errors in the magnitude of 10 to 50 meters over a distance of 400 meters are not uncommon. This not only results in additional costs, but sometimes also in (near) environmental disasters. Such disasters may happen when the drilling takes place in the vicinity of underground electrical cables or oil and gas pipes. In view of the above mentioned disadvantages of present day guidance systems there exists a need to improve the horizontal directional drilling accuracy to become more reliable, more accurate, more easy to use, immune for magnetic interference and to have measurement data continuously available even while drilling.

Summary of the Invention

[0003] It is an object of the invention to provide a guidance system for a horizontal directional drilling system comprising sensors at the drill head, which sensors comprise at least one of the sensors: fiber optic gyroscope, ring laser gyroscope, micro-electro-mechanical system, rate sensor.

[0004] A further object of the invention is to provide such a guidance system further comprising in microcontroller for receiving and processing data from sensors at the drill head.

[0005] A still further object of the invention is to provide such a guidance system in which the microcontroller comprises neural fuzzy control logic for processing the data from the sensors at the drill head.

[0006] A still further object of the invention is to provide such a guidance system in with the microcontroller further comprises means for application of model-based deterministic and stochastic, respectively, filtering techniques to the data from the sensors at the drill head. Thereby a magnetic interference canceling adaptive filter is obtained.

[0007] A still further object of the invention is to provide such a system in which the sensor further comprises at least one of a magnetometer and an accelerometer and at least one rate sensor and means for integrating signal from the rate sensor.

[0008] Further object of the invention is to provide such a system comprising a magnetometer and a rate sensor measuring rate of change of azimuth and further comprising means for controlling the system in dependence on an integrated change of rate of azimuth signal when a magnetic interference is present.

[0009] A still further object of the invention is to provide such a system comprising at least one accelerometer and at least one rate sensor for measuring a rate of change of the same quantity that is measured by the at least one accelerometer and further comprising means for from time to time resetting the rate sensor and/or an integrated rate of change of the relative quantity signal.

[0010] It is also an object of the invention to provide such a system further comprising transmitting means for transmitting data from an output of the microcontroller to a surface device, which surface device comprises a computer and display device and which computer is programmed with a user interface to display at least one of azimuth, tilt and inclination angles of the drill head on the display device.

[0011] An other object of the invention is to provide such a system further comprising at least one rate sensor and transmitting proces data from an output of the microcontroller to a surface device, means for determining a reliability figure for data dependent on integrated signals from the rate sensor, which surface device comprises a computer and a display device and which computer is programmed with a user interface to display the reliability figure.

[0012] A further object of the invention is to provide such a guidance system in which the computer is further programmed to display guidance instructions in case the reliability figure is smaller than a predetermined minimum.

Brief description of the drawings

[0013] The invention will now be described in greater detail below with reference to the drawings in which:

Figure 1 shows schematically a down-hole probe near a drill head with various elements of a guidance system according to the invention;
Figure 2 shows a vector exemplary of the direction of the earth magnetic field relative to the earth surface;
Figure 3 shows a first embodiment of a sensor unit;
Figure 4 shows a second embodiment of a sensor unit;
Figure 5 shows a third embodiment of a sensor unit;
Figure 6 shows a fourth embodiment of a sensor unit;
Figure 7 shows a fifth embodiment of a sensor unit.

Detailed description of the invention

[0014] Referring to Figure 1 an earth surface 1 is shown. Beyond the surface 1 and in the earth 2 a bore hole is being made according to the horizontal directional drilling method. A drill head (not shown) is provided with a probe, schematically indicated by the reference number 3, which is part of a guidance system guiding the drill head through the earth 2 and, since it is at the front of the bore hole, is called a down-hole probe. At the earth surface 1 the guidance system comprises a computer 4 with a keyboard 5 and a monitor 6. The down-hole probe 3 comprises a power source 7, a transmitter 8, a microcontroller 9 and a sensor unit 10 comprising one or more sensors. The power source 7 may comprise a battery and/or electric DC power supplies. Power is supplied to the transmitter 8, the microcontroller 9 and the sensor unit 10. Signals from sensor unit 10 are input tot microcontroller 9 as indicated by arrow 11. Output signals from microcontroller 9 are input to transmitter 8, as indicated by arrow 12. Arrow 13 indicates a connection between transmitter 8 and computer 4. The connection between transmitter 8 and computer 4 may be a wire connection but preferably is a radio-wave connection. Computer 4 calculates, based upon signals transmitted by transmitter 8, signals which are data and other information generated by microcontroller 9, guidance signals for the horizontal directional drilling system of which the down-hole probe 3 is a part. The outputting of guidance signals by computer 4 to the horizontal directional drilling system, schematically indicated by the reference number 14, has been schematically indicated

by arrow 15.

[0015] As has been described before traditional horizontal directional drilling systems 14 comprise as sensors a magnetometer 16 and an accelerometer 17 for measuring the tilt angle and an accelerometer 18 for measuring the inclination angle (see Figure 3), all inside down-hole probe 3.

[0016] In order to achieve the objects of the present invention use is being made of various elements, some of which are already known as such, but have never been used or proposed for use in horizontal directional drilling systems. Such elements comprise fiber optic gyroscopes, ring laser gyroscopes, micro-electro-mechanical systems, rate sensors and fuzzy logic. Those elements either alone or in combination with each other and/or in combination with magnetometers and/or accelerometers are able to make a horizontal directional drilling system achieve the requirements mentioned hereinbefore relating to reliability, accuracy, ease of use, immunity to magnetic field interferences and continuity of availability of measurement data, even while drilling.

[0017] Fiber optic gyroscopes and ring laser gyroscopes are elements in which two lightbeams travel in opposite directions around a common path. When the plane of the path rotates a relative phase shift will occur between the two lightbeams travelling in opposite directions. In a ring laser gyroscope the phase shift is measured which is due to an inherent change in oscillation frequency. In a fiber optic gyroscope the phase shift is measured by interference techniques. Both types of gyroscopes allow to measure yaw-rate, pitch-rate and roll-rate. When such gyroscopes include integration circuits output signals of such gyroscopes deliver output signals that are representative of for example an azimuth angle, a tilt angle, or an inclination angle. External dimensions of fiber optic gyroscopes and ring laser gyroscopes are substantially smaller than corresponding dimensions of mechanical gyroscopes. Ring laser gyroscopes and fiber optic gyroscopes are sufficiently small to be integrated in a sensor package 10 of a drill head. They also have as advantages over mechanical gyroscopes no run up time, higher accuracy and far higher reliabilities. Ring laser gyroscopes and fiber optic gyroscopes are able to operate in a rotating drill head guidance assembly, whereas mechanical gyroscopes are not suited for such harsh environments. Accuracy of a fiber optic gyroscope can be in the magnitude of 0.01 degree for ambient temperature ranges from -40 to +80 degrees Centigrade. As is to be expected fiber optic gyroscopes and ring laser gyroscopes are insensitive to magnetic interference.

[0018] Rate sensors as such are available in the market place and are based on principles that range from Coriolis fork gyro to hybrid solutions. Rate sensors are sensors that deliver output signals that are representative of changes of a measured quantity per unit of time. In order to obtain an integrated value such output signals have to be integrated over time. When for example a rate sensor is used to determine the rate at which an inclination angle changes with the time the inclination angle at a certian point of time is obtained by integrating the rate signal. Generally the integrated signal will slowly walk away, depending on resolution, temperatue sensitivity etcetera of the relative rate sensor. Typical resolutions achievable by rate sensors are in the magnitude of 0.01 degree per sec to 1 degree per hour. The external dimensions of rate sensors generally are sufficiently small for integrating such rate sensors in a down-hole probe of a horizontal directional drillign system.

[0019] Drill head angles can be calculated from the signals delivered by the beforementioned magnetometers, accelerometers, fiber optic gyroscopes, ring laser gyroscopes, micro-electro-mechanical systems and rate sensors. Data from all those sensors must be intelligently combined to achieve a reliable output for the drill head angles, regardless of magnetic interference, or other disturbing circumstances. All these calculations can be very complicated. Good results can be achieved when these calculations are being carried out by using so called neural fuzzy control methods. Preferably these calculations are carried out by a microcontroller 9 which is part of the down-hole probe. In that case the connections between the sensors and the calculating logic are very short and chances are minimal for the sensor signals to be contaminated with noise signals from other sources. By carrying out calculations on the signals delivered by the sensors to the microcontroller 9 through line 11 and by applying deterministic and stochastic, respectively, filtering techniques a magnetic interference canceling adaptive filter is obtained.

[0020] Various combinations of sensors in the sensor unit 10 will now be described.

[0021] Figure 4 shows a sensor unit 10 comprising three fiber optic gyroscopes 19, 20 and 21. It is to be noted that instead of fiber optic gyroscopes the gyroscopes 19, 20 and 21 may also be ring laser gyroscopes, the only difference being the physics way in which a phase shift is measured. Unless otherwise mentioned any time that a fiber optic gyroscope is mentioned it is to be noted that in place of a fiber optic gyroscope a ring laser gyroscope could be used in that same place. The fiber optic gyroscopes 19, 20 and 21 are placed each in a plane from which can be measured the azimuth angle, the pitch angle and the inclination angle, respectively. For example, fiber optic gyroscope 19 may measure azimuth angle, fiber optic gyroscope 20 may measure tilt angle and fiber optic gyroscope 21 may measure inclination angle. Since fiber optic gyroscopes measure angles by integrating rate of change of angle offset values have to be input into the control system. After the offset angles have been input into the control system the fiber optic gyroscopes 19, 20 and 21 deliver the required angle values. Those angle values are sent over line 11, which of course may be a multiple line, to the microcontroller 9 for calculating purposes. Thereafter calculated values are sent over line 12 to transmitter 8. The calculated values that are input into transmitter

8 via line 12 are transmitted, for example by radio-signal, over line 13 to computer 4. Computer 4 may be a regular personal computer with a keyboard 5 an a monitor 6. Due to the accuracy of fiber optic gyroscopes the sensor unit 10 in principle does not need any more sensors than the three fiber optic gyroscopes 19, 20 and 21.

[0022] Figure 5 shows a further embodiment of the sensor unit 10. The sensor unit 10 comprises again three fiber optic gyroscopes 19, 20 and 21 and in addition thereto accelerometers 22 and 23. Accelerometer 22 measures a tilt angle and accelerometer 23 measures an inclination angle of the drill head. The signals from the accelerometers 22 and 23 can be used in the microcontroller 9 to determine offset values for the fiber optic gyroscopes, for example fiber optic gyroscopes 20 and 21 that measure tilt angle and inclination angle, respectively.

[0023] Figure 6 shows a further embodiment of sensor unit 10. The sensor unit 10 shown in Figure 6 comprises a magnetometer 24, a yaw-rate sensor 25, a roll-rate sensor 26 and a pitch-rate sensor 27. It also comprises an accelerometer 22 and an accelerometer 23. Magnetometer 24 and yaw-rate sensor 25 cooperate. When there is no magnetic interference magnetometer 24 may determine the azimuth angle. However when there is magnetic interference the magnetometer output will drift away. Such drift will be communicated through line 11 to microcontroller 9 and from microcontroller 9 to line 12 to transmitter 8 and from transmitter 8 to line 13 to computer 4. Computer 4 will use the data generated by microcontroller 9 and based upon output signals from the magnetometer 24, which output signals have drifted away to control through line 15 the drill head 16. The drift in output signal of the magnetometer will result in drifting away in direction of the drill head 16. Such drifting away of the drill head 16 will be sensed by rate sensor 25. Microcontroller 9 will determine that rate sensor 25 generates a signal where it should not generate a signal and passes this information to computer 4. That will determine that rate sensor 25 has sensed an ongoing change in azimuth angle whereas magnetometer 24 has not sensed such change and computer 4 will determine that a drift is present in the output signal of the magnetometer which should not be translated into a change in the azimuth angle of the drill head 16. Most underground magnetic interference is due to various materials. These various materials normally have influence on the horizontal directional drilling system and its sensor during a limited period of time. Those magnetic interferences therefore also are very much locally. During those periods of magnetic interference the control of the drill head 16 will not be based upon output signals of the magnetometer 24 but on integrated output signals of yaw-rate sensor 25.

[0024] Nevertheless integrating the signals from the yaw-rate sensor 25 will lead to slowly walking away of the integrated signals, depending upon resolution, temperature sensitivity etcetera of the rate sensor 25. Therefore control of the direction of the drill head 16 by computer 4 based upon signals from yaw-rate sensor 25 should only be done for a limited period of time. Present yaw-rate sensors limit such period to a maximum of about half an hour when the resolution of the rate sensor is 1 degree per hour. Offset of the yaw-rate sensor, which takes place for example in the microcontroller 9, may for example be based upon the reading of the magnetometer at the point of time that it is decided to take over the directional control of the drill head 16 from the signals from the magnetometer 24 to control based upon the signals from the yaw-rate sensor 25.

[0025] The rate signals generated by the rate sensors 26 and 27 may be integrated to provide inclination angle and tilt angle of the drill head. As with rate sensor 25 the integrated signals of the rate sensors 26 and 27, which integration may take place in the microcontroller 9, will slowly walk away depending upon the resolution, temperature sensitivity etcetera. These walk away effects can be compensated by use of the accelerometers 22 and 23. Each time that drill head rotation is stopped to steer the drill head in a certain direction, which stopping happens periodically, the accelerometers will give accurate values for the tilt and inclination angles. The results of these measurements of tilt- and inclination angle can be used to, automatically, offset the rate sensors 26 and 27.

[0026] Hereinbefore it has been assumed that at a certain position of the drill head it is known that magnetic interference exists at that location. The existence of such magnetic interference is not detected by the magnetometer 24 itself. However two methods will be described hereinafter to determine the presence of magnetic interference, i.e. the presence of a magnetic field of sufficient strenght to make the magnetometer measure a value and direction of a magnetic field that is not identical to the value and direction of the earth magnetic field at that location.

[0027] Figure 2 shows a coordinate system in which the drill head is considered to be in the origin and the earth magnetic field is expressed as a vector 28. One of the axes, indicated by the letter N, is directed to true North. Angle δ indicates the deviation of the magnetic North MN from the true North N and angle 29 indicates the angle of dip of the earth magnetic field relative to the surface of the earth which corresponds to the x-y plane of the coordinate system shown in figure 2.

[0028] A first device to determine the presence of magnetic interference comprises two magnetometers at a few meters distance from each other in the down-hole probe. Preferably those magnetometers are 3-axis magnetometers measuring components of the earth magnetic field in three mutually orthogonal directions, but this is not a necessity in this first embodiment. In first instance both magnetometers determine the azimuth angle at their locations a few meters apart. In case the magnetometers give the same output signal it can be assumed that there is no magnetic interference at that

location. In case the magnetometers give different outputs at least one of the two manetometers is in a location in which there is magnetic interference.

[0029] A second device for determining the presence of magnetic interference comprises one or even two 3-axis magnetometers. 3-axis magnetometers are able to determine not only the direction of the magnetic North, i.e. the azimuth angle, but also the angle of dip 29. The angle of dip 29 is known as such for all locations in the world. A single measurement with a 3-axis magnetometer may suffice to determine the angle of dip. As the angle of dip measured by a single magnetometer differs from the angle of dip that should be present due to the location on the earth where the drilling takes place, that is an indication that there is magnetic interference. In case two 3-axis magnetometers are being used a comparison can be made between the true directions of the vectors 28, one measured by each magnetometer. In case a difference in direction exists between the vector 28 as measured by a first 3-axis magnetometer from the vector 28 as measured by a second 3-axis magnetometer that is a very strong indication that a magnetic interference exists at that location.

[0030] A sensor unit 10 that may be used to determine the presence of magnetic interference is shown in figure 7 and comprises two magnetometers 24a en 24b. As hereinbefore the sensor unit 10 also comprises rate sensors 25, 26 and 27 and accelerometers 22 and 23 for the purposes described in relation to figure 6. When no magnetic interference is present either one of the magnetometers 24a or 24b can be used in a same way as magnetometer 24 was used in the system described in relation with figure 6. Both embodiments shown in figures 6 and 7 have the possibility of having the yaw-rate sensor 25 being automatically off-set from time to time by the magnetometer 24 and 24a, 24b respectively. In that way, when a magnetic interference comes up and control of the drill head has to be based on integration of the signal from the yaw-rate sensor 25 that signal can be used reliably. The reliability of the signal from the yaw-rate sensor 25 decreases with increasing periods of time since the last point of time that it was reset by the signal from magnetometer 24 or one of the magnetometers 24a and 24b.

[0031] As described hereinbefore rate sensors have offsets and after integration may show drift in their output signals. Contrary thereto accelerometers show a stable output as function of time. A gravity angle determined from an accelerometer can therefore be used to compensate a rate sensor. That results in a drift free rate measurement. Such a drift free rate measurement again can be used to correct an output of a magnetometer in case of magnetic interference. However not in all circumstances traditional accelerometers can be used to achieve this result.

[0032] Traditional accelerometers have resolutions in the magnitude of 5 micro g. and temperature coefficients in the magnitude of 75 micro g per degree Centigrade. A typical time constant of a traditional accelerometer is 0.13 seconds. A rotational speed of a drill head typically is approximately 20 RPM, which equals 120 degrees per second. Therefore typically traditional accelerometers have a time constant that is too large to be used in magnetometer compensation in case of magnetic interference. Present micro-electro-mechanical system sensors do show time constants in the magnitude of 1 millisecond. Hence these sensors can be used to enhance the magnetometer response and accuracy.

[0033] It is extremely difficult to employ skilled staff having sufficient knowledge about the measurement techniques and their inter relationship with the directional control of the drill head. User interfaces, i.e. computer programs on the computer 4 that allow an operator to enter correct commands through the keyboard or other data entry elements such as a mouse, should therefore be simple and easy to understand. For example in an abnormal situation, such as magnetic interference, easy to understand guidance must be given to the operator.

[0034] Raw data are sent by microcontroller 9 to computer 4 once every so many seconds. A program in computer 4 translates those raw data into signals for the monitor 6 to display the azimuth, tilt, and inclination angle. It also shows the position of the toolface, which is of importance while steering. In general these presentations of data require various skilled staff for interpretation. Improvement is required. For example when applying fiber optic gyroscopes as sensors it is easy, due to their high accuracy, to display reliable true North data and to calculate, by dead-reckoning, the precise position of the drill head. It is also possible then to show on the monitor 6, by means of a suitable programme, both the actual and the desired track. This may in particular be of importance when underground curves are being made by the drill head. With the accurate sensor systems described hereinbefore for use in a horizontal directional drilling system, it is possible to steer the drill head at desired locations to make underground curves.

[0035] In certain of the embodiments described hereinabove rate sensors were applied. It is known that integrated rate sensor signals will slowly walk away depending on resolution, temperature sensitivity etcetera. Therefore the more time has elapsed between the last point of time that the integrated value of a rate sensor was reset the less reliable is a present value of the integrated signal. A program displaying integrated signals of rate sensors, or of other signals that depend on integrated signals from rate sensors, will therefore be displayed on monitor 6 together with a reliability figure. The reliability figure informs an operator of the measure of reliability of the displayed figures. In a situation in which one or more of the figures displayed on monitor 6 are displayed with a reliability figure that is out of range, i.e. the reliability figure shows that the reliability is below a certain minimum reliability figure then the operator should switch to another method of control of steering the drill head, for example by following instructions gen-

erated by the computerprogram and displayed on the screen of the monitor 6.

[0036] After the above descriptions various modifications and alterations will become clear to a person skilled in the art. Such modifications and alterations are considered to be within the scope of the appended claims.

Claims

1. Guidance system for a horizontal directional drilling system comprising sensors at a drill head, which sensors comprise at least one of the sensors: fiber optic gyroscope, ring laser gyroscope, micro-electro-mechanical system, rate sensor.

2. System according to claim 1 further comprising a microcontroller for receiving and processing data from sensors at the drill head.

3. System according to claim 2 in which the microcontroller comprises fuzzy control logic for processing the data from the sensors at the drill head.

4. System according to claim 3 in which the microcontroller further comprises means for application of deterministic approaches and filtering techniques to the data from the sensors at the drill head.

5. System according to claim 2 comprising transmitting means for transmitting processed data from an output of the microcontroller to a surface device.

6. System according to claim 5 in which transmitting takes place by means of wireless communication.

7. System according to claim 5 in which the surface device comprises a computer.

8. System according to claim 7 in which the surface device comprises a display.

9. System according to claim 7 in which the surface device comprises a data entry means.

10. System according to claim 9 in which the data entry means comprise a keyboard.

11. System according to claim 1 in which the sensors further comprise at least one of a magnetometer and an accelerometer.

12. System according to claim 11 comprising at least one rate sensor and means for integrating a signal from the rate sensor.

13. System according to claim 12 comrprising a magnetometer and a rate sensor measuring rate of change of azimuth and further comprising means for controlling the system in dependence on an integrated change of rate of azimuth signal when a magnetic interference is present.

14. System according to claim 12 comprising at least one accelerometer and at least one rate sensor for measuring a rate of change of the same quantity that is measured by the at least one accelerometer and further comprising means for from time to time resetting the rate sensor and/or an integrated rate of change of the relative quantity signal.

15. System according to claim 2 further comprising transmitting means for transmitting data from an output of the microcontroller to a surface device, which surface device comprises a computer and a display device and which computer is programmed with a user interface to display at least one of azimuth, tilt and inclination angles of the drill head on the display device.

16. System according to claim 15 which system comprises at least one fiber optic gyroscope or at least one ring laser gyroscope and means for displaying on the display device true North.

17. System according to claim 15 which system comprises at least one fiber optic gyroscope or at least one ring laser gyroscope and means for displaying on the display device an actual and a desired track.

18. System according to claim 2 further comprising at least one rate sensor and transmitting processed data from an output of the microcontroller to a surface device, means for determining a reliability figure for data dependent on integrated signal from the rate sensor, which surface device comprises a computer and a display device and which computer is programmed with a user interface to display the reliability figure.

19. System according to claim 18 in which the computer is further programmed to display guidance instructions in case the reliability figure is smaller then a predetermined minimum.

20. System according to claim 1 comprising two magnetometers, at least one accelerometer and at least one rate sensor.

21. System according to claim 20 further comprising a microcontroller for receiving and processing data from the two magnetometers, the at least one accelerometer and the at least one rate sensor, in which the two magnetometers are spaced apart for a certain distance and generate first and second

output signals, respectively and the microcontroller comprises means for determining a difference between the first and second output signals of the two magnetometers.

22. System according to claim 21 further comprising means for integrating output signals of the at least one rate sensor and for from time to time resetting integrated output signals of the at least one rate sensor based upon output signals of the at least one accelerometer.

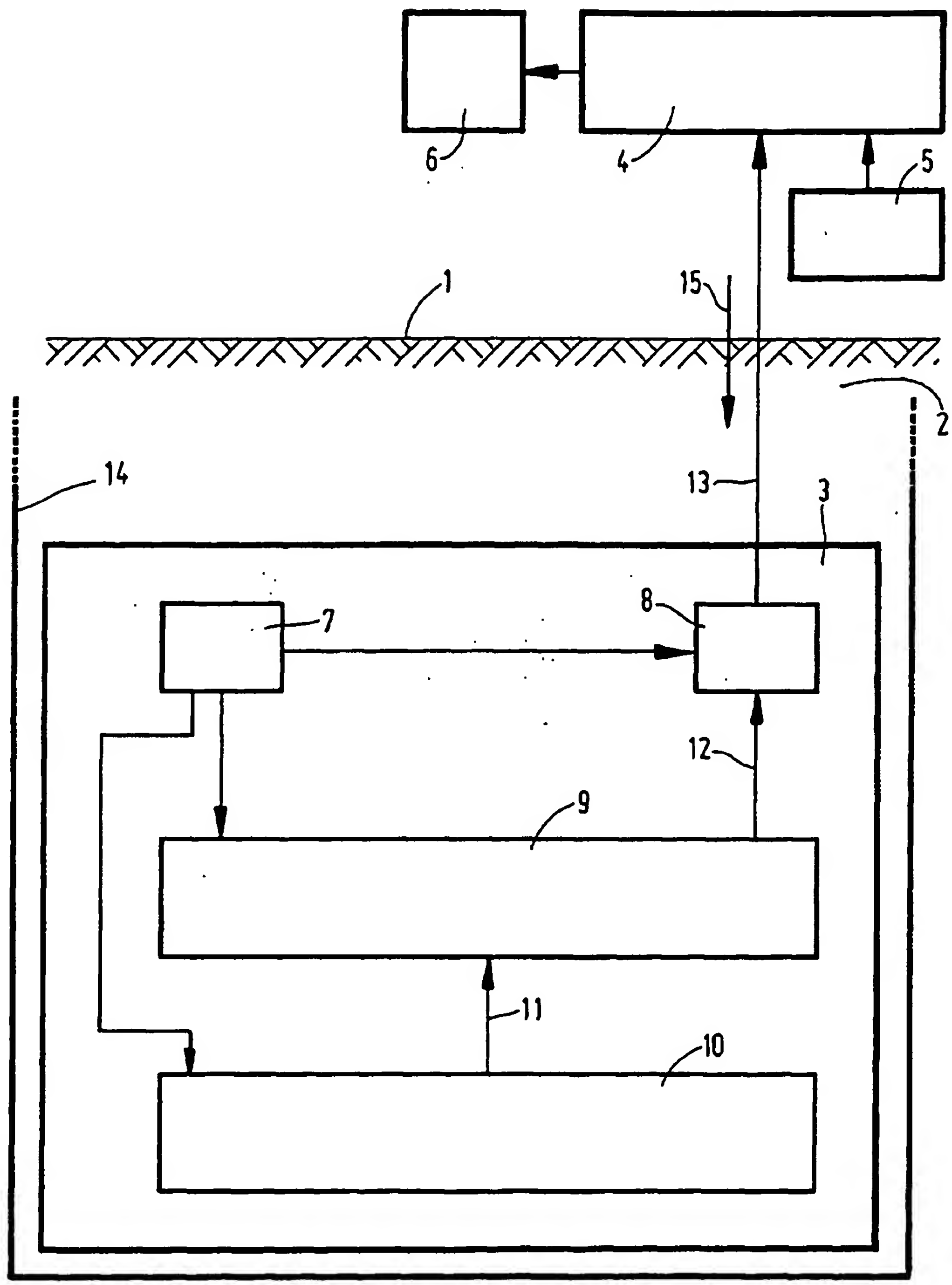

FIG. 1

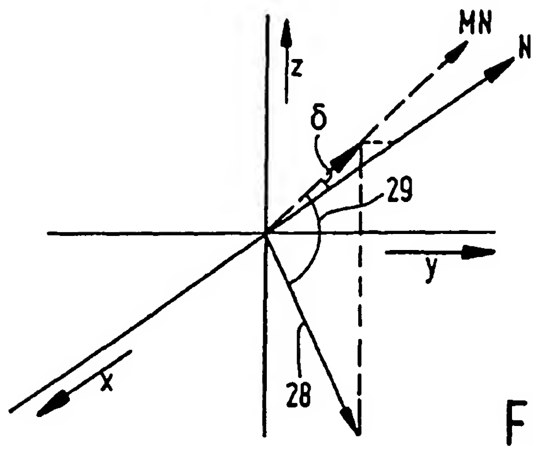

FIG. 2

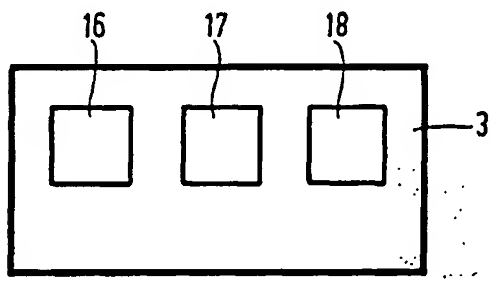

FIG. 3
(PRIOR ART)

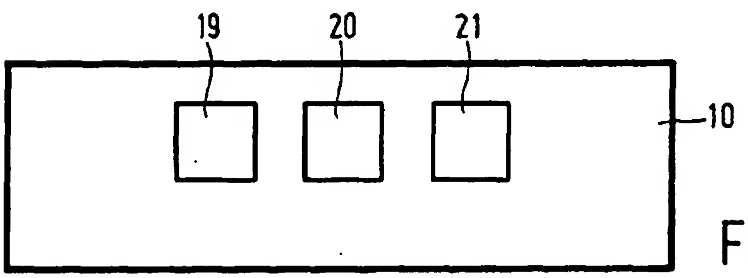

FIG. 4

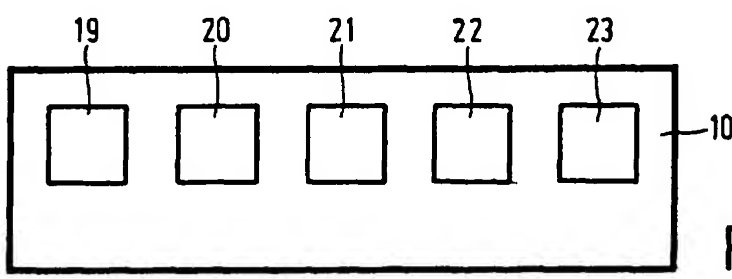

FIG. 5

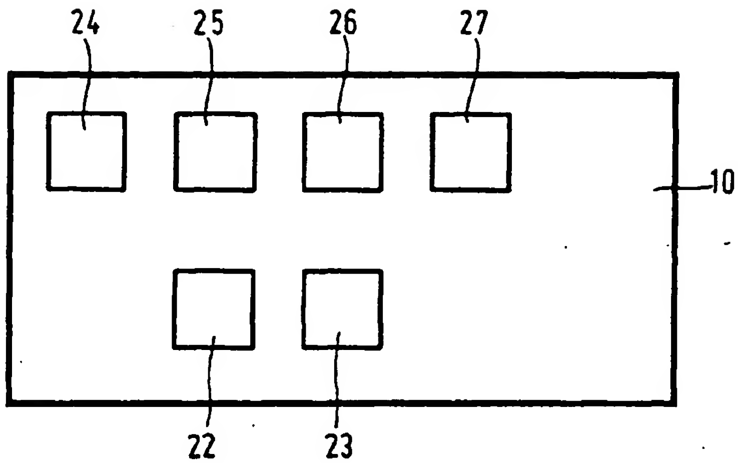

FIG.6

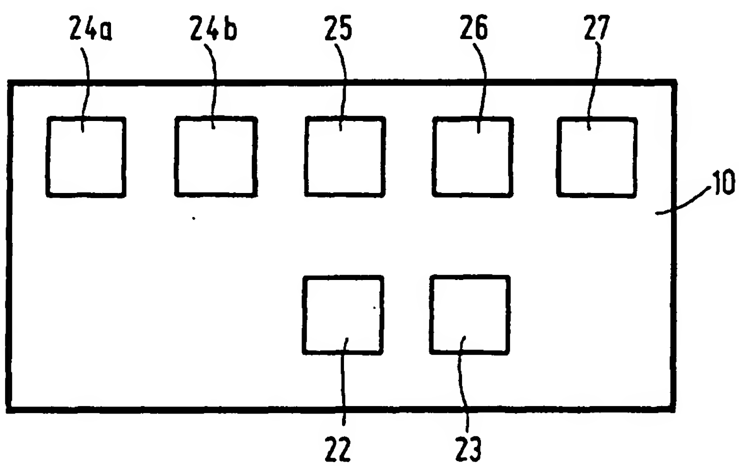

FIG.7

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The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
MUNICH	21 May 2001	Tompouloglou, C

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